acta
geologica
polonica

Vol. 34, No. 3-4 Warszawa 1984

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A new species of sea pens, *Graphularia transaedina* sp. n., from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland)

ABSTRACT: The Middle Miocene (Badenian) Korytnica Clays exposed within the Korytnica Basin (southern slopes of the Holy Cross Mountains, Central Poland) yielded a rich assemblage of the sea pens. All the collected material, composed of the fragmented axial rods of endoskeletons, belongs to a new species, *Graphularia transaedina* sp. n. An analysis of the microstructure allowed to discuss a relation of the investigated species and other representatives of the extinct genus *Graphularia* MILNE-EDWARDS & HAIME, 1850, to the Recent pennatulacean octocorals.

INTRODUCTION

The octocorals of the order Pennatulacea, currently called the sea pens, are a common component of various shallow marine communities of Recent seas. In the fossil state they are however extremely rare, what is caused by a weak development of the mineral endoskeleton composed of loose sclerites and sometimes associated with a more or less solid axial rod running inside the primary oozooid. Such very axial rods have recently been recognized by the authors in sifted samples from the world-famous Korytnica Clays (Middle Miocene, Badenian), developed within the Korytnica Basin on the southern slopes of the Holy Cross Mountains, Central Poland. The collected specimens have been assigned to the genus *Graphularia* MILNE-EDWARDS & HAIME, 1850. The remnants of sea pens have neither been reported within the diversified organic communities of these extremely fossiliferous Clays nor from any other fossil-bearing localities of the Middle Miocene (Badenian) deposits of the Fore-Carpathian area to which the Middle Miocene (Badenian) basin belonged (*cf.* BAŁUK & RADWAŃSKI 1977).

THE INVESTIGATED MATERIAL

The fragments of the axial rods are present in many samples of the Korytnica Clays, but a more common occurrence has been noted only in three localities (Text-fig. 1). All the collected specimens are small fragments, less than 10 mm in length (*see* Pl. 1, Figs 1—7), and only samples from one of these localities (*2* in Text-fig. 1) have yielded larger fragments, about 20 mm long (*see* Pl. 1, Fig. 7a). The specimens from localities *2* and *3* are usually thicker (c. 2 mm in diameter), whilst those from the locality *1* are almost twice thinner; the recognized size differences are supposedly related to the ontogenic age of pennatulaceans preserved in the investigated samples.

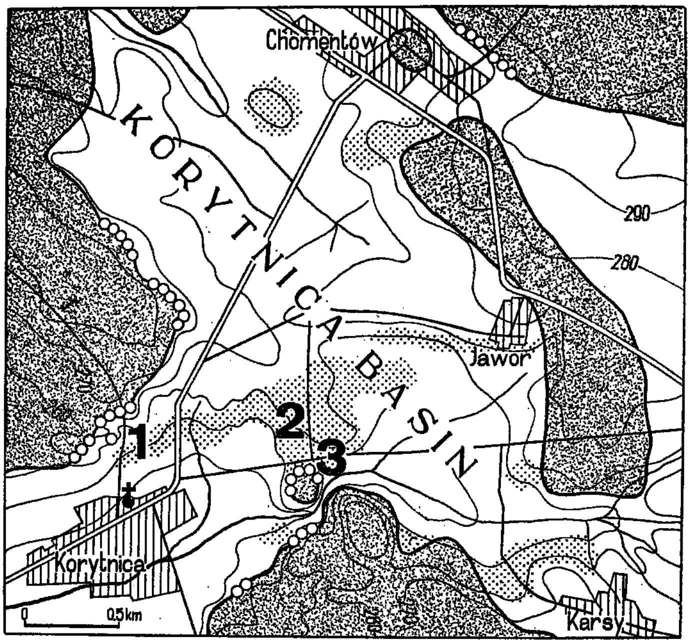

Fig. 1. Paleoenvironmental sketch of the Korytnica Basin (*adopted from:* BAŁUK & RADWAŃSKI 1977, Text-fig. 2)

Indicated are: marine area of the Korytnica Basin during the Middle Miocene (Badenian) transgression (*blank*) and present-day outcrops of the Korytnica Clays (*stippled*), preserved fragments of littoral structures (*circled*), and land or island areas along the seashore (*hachured*)

The occurrence sites of the investigated sea pens, *Graphularia transaedina* sp. n., are indicated: **1** — Korytnica-Plebania (site behind the priest's house at the church), **2** — north of Mt. Lysa, **3** — littoral facies (oyster shellbed) along the island slopes (Mt. Lysa in present-day morphology)

Most of the specimens are well preserved, and this allowed to undertake an analysis of their microstructure under the scanning electron microscope, the method having not been hitherto used for the ancient pennatulaceans. A few data presented by BAYER (1955) and SHAPIRO & RAMSDELL (1965) on some *Graphularia* were obtained by the studies of thin sections under the optical microscope. The *SEM* data given by FRANC, HUC & CHASSAGNE (1974) and LEDGER & FRANC (1978) for the present-day species *Veretillum cynomorium* (PALLAS) are the only exception offering satisfactory recognition of the axial rods of any pennatulaceans.

ENVIRONMENTAL NOTE

The Recent sea pens live always on the muddy or sandy bottoms, ranging from the littoral zone to greater depths, under diverse climatic conditions (KÜKENTHAL 1915).

The Korytnica Clays have been deposited within a larger bay, the Korytnica Bay, which extended along the southern slopes of the Holy Cross Mountains (*cf.* RADWAŃSKI 1969, BAŁUK & RADWAŃSKI 1977). All the pennatulacean-bearing localities are situated near the recognized shoreline (*see* Text-fig. 1). The fossils associated to the investigated sea pens are indicative of extremely shallow marine conditions and of tropical and/or subtropical climatic conditions, as it is evidenced by the bivalved gastropods of the genus *Berthelinia* found in all three localities, and coral-inhabiting barnacles of the genus *Creusia* present in localities *1* and *2* (references *in:* BAŁUK & JAKUBOWSKI 1968, *and* BAŁUK & RADWAŃSKI 1967, 1977, 1984).

SYSTEMATIC ACCOUNT

Class **Anthozoa** EHRENBERG, 1834
Subclass **Octocorallia** HAECKEL, 1866
Order **Pennatulacea** VERRILL, 1865
(Suborder and family uncertain)
Genus *Graphularia* MILNE-EDWARDS & HAIME, 1850

Graphularia transaedina sp. n.
(Pls 1—8)

HOLOTYPE: The specimen presented in Pl. 1, Figs 3a—3b.

PARATYPES: The specimens presented in Pl. 1, Figs 1—2 and 4—7.

TYPE LOCALITY: Korytnica, 24 km SSW of Kielce, southern slopes of the Holy Cross Mountains, Central Poland.

TYPE HORIZON: Middle Miocene (Badenian).

DERIVATION OF THE NAME: Latin *trans* — behind, and *aedes* — priest's house at the church; after the first place of finding, being a cropland of the church property (locality *1* in Text-fig. 1).

DIAGNOSIS: Axial rods straight, or slightly bending in longer fragments, quadrangular in transverse section, with rounded corners; central core composed of numerous, densely spaced egg-shaped granules; cortical zone of a few concentric layers, composed of radially arranged columnar to fan-shaped calcite crystals extending from the central core.

MATERIAL: Over a hundred fragmented specimens.

DIMENSIONS: The largest fragment (Pl. 1, Figs 7a—7b) attains 19 mm and is 2.5 mm wide; the greatest width in other specimens is 4 mm, the smallest is 0.7 mm.

DESCRIPTION: The investigated axial rods are straight, without any taperings. The walls of the axial rods are usually slightly convex (Pl. 1, Fig. 6b), but sometimes become almost flat or indistinctly concave (as in the holotype — Pl. 1, Fig. 3b). The external surface is sculptured by extremely fine and delicate, but densely spaced longitudinal grooves, commonly discontinuous, bifurcating or anastomosing, and thus making up a much elongated braided pattern. The transverse section is quadrangular, with rounded corners (Pl. 1, Fig. 3b), sometimes slightly trapezoidal (Pl. 1, Fig. 2b).

MICROSTRUCTURE: The investigated axial rods are composed of gray-brown, cloudy, and pseudopleochroic calcite arranged in concentric growth layers of the cortical zone (Pl. 2, Figs 2a-c; Pl. 6, Fig. 1b). Under crossed nicols, columnar to fan-shaped calcite crystals, perpendicular to the axial rod (Pl. 3, Figs 1a-b, 2—5), show undulose light extinction. The central core contains numerous egg-shaped granules (Pl. 2, Figs 1a, c; Pl. 4, Figs 1a-b; Pl. 6, Fig. 1b; Pl. 8, Figs 3—5), in average 22 μm long and 15 μm thick; their surface is porous and shows densely spaced canals after collagen fibrils (Pl. 8, Figs 4—5), more or less parallel to their longer axis. The calcite crystals within the cortical zone originated by unidirectional growth of granules as it was observed (FRANC, HUC & CHASSAGNE 1974; LEDGER & FRANC 1978) in the present-day pennatulacean species *Veretillum cynomorium* (PALLAS).

In transverse sections, displayed are radially arranged calcite crystals, the majority of which are continuous through the whole cortical zone, and some start and stop their growth at different places. The crystals, continuing through the growth layers (Pl. 2, Fig. 2b; Pl. 3, Fig. 3), are shorter and more numerous near the central core, whilst towards the outer edge they are more elongated and less numerous. The *SEM* pictures show two types of holes: small (diameter up to 0.2—0.4 μm) ones, arranged in a very dense manner, are the openings of canals after collagen fibrils (Pl. 6, Fig. 1c), and larger ones (up to 2—7 μm wide and 25—100 μm long), arranged perpendicularly, are the cavities after chimney cells (Pl. 2, Fig. 2c; Pl. 6, Figs 1a—c). Some of the latter reach the outer surface of the axial rod, where they are visible as holes (Pl. 8, Figs 1a—b, 2).

In longitudinal sections, the main character is a very delicate striation (Pl. 2, Fig. 3). The *SEM* pictures reveal that these striae are really very thin canals after collagen fibrils (Pl. 5, Figs 1a—b), the openings of which are visible on transverse surfaces. These canals are roughly parallel each other and continue probably along the whole axial rod. On the longitudinally arranged broken surfaces, the cavities after chimney cells appear to be perpendicular to the cortical zone only near the central core (Pl. 4, Fig. 1a), whereas in the middle of the zone they are directed oblique-upwardly (Pl. 5, Fig. 1a); these cavities are narrow and elongated, with their acute tips directed outwards, and the broader opposite tips inwards.

REMARKS: Comparison of the newly established species, *Graphularia transaedina* sp. n., with other species of the genus is not possible, as none of them has hitherto been surveyed with data on the microstructure of the axial rod.

The investigated specimens of *Graphularia transaedina* sp. n. are certainly close to those of the quadrangled transverse section. A similarity is displayed to a part of the type specimens of *Graphularia wetherelli*, precisely to those with very

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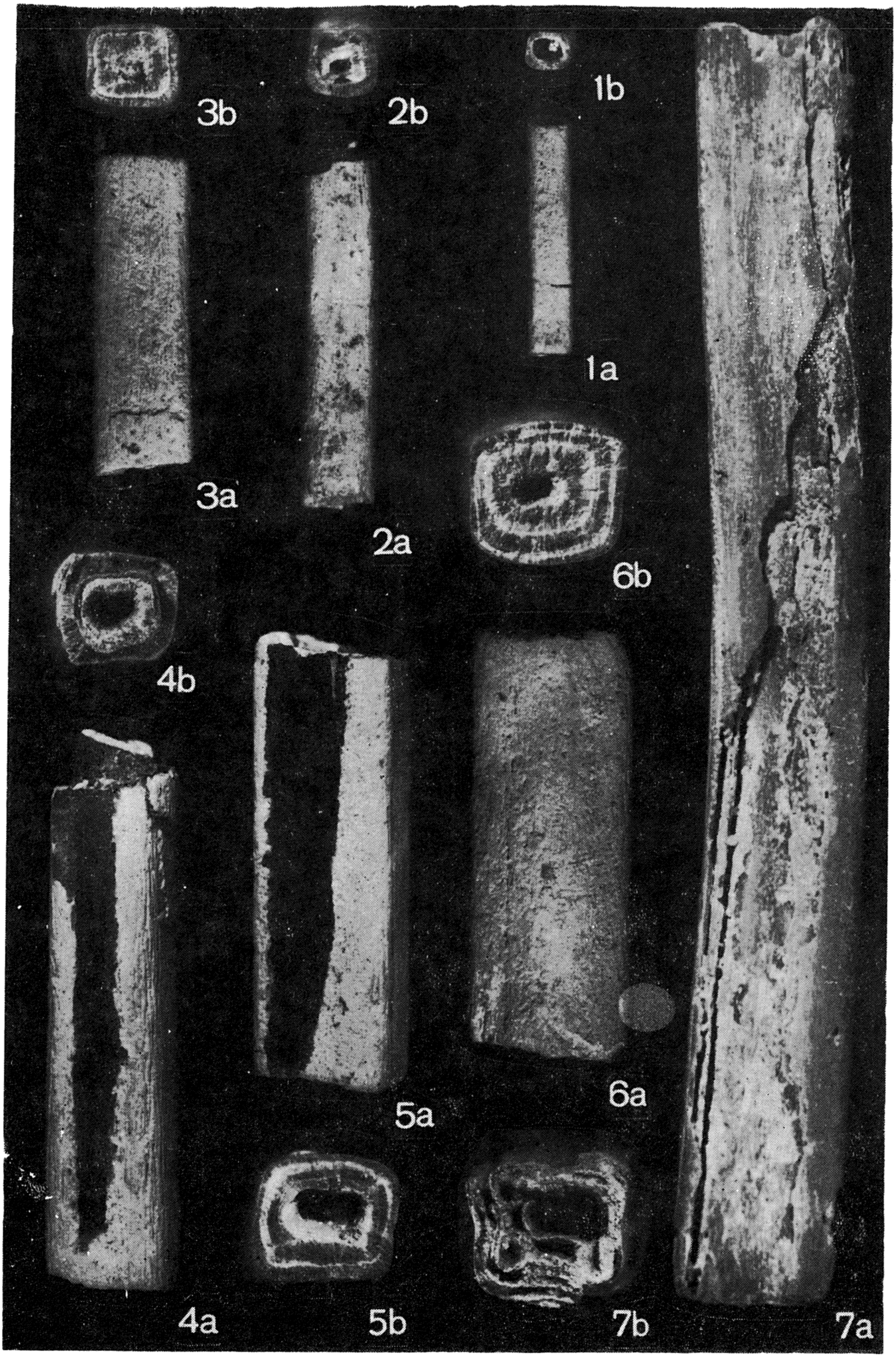
PLATE 1

1-7 — *Graphularia transaedina* sp. n. from the Korytnica Clays (3 presents the holotype); 1a-7a — side views, 1b-7b — views of transverse broken surface

All photos × 10; taken by L. ŁUSZCZEWSKA, M. Sc.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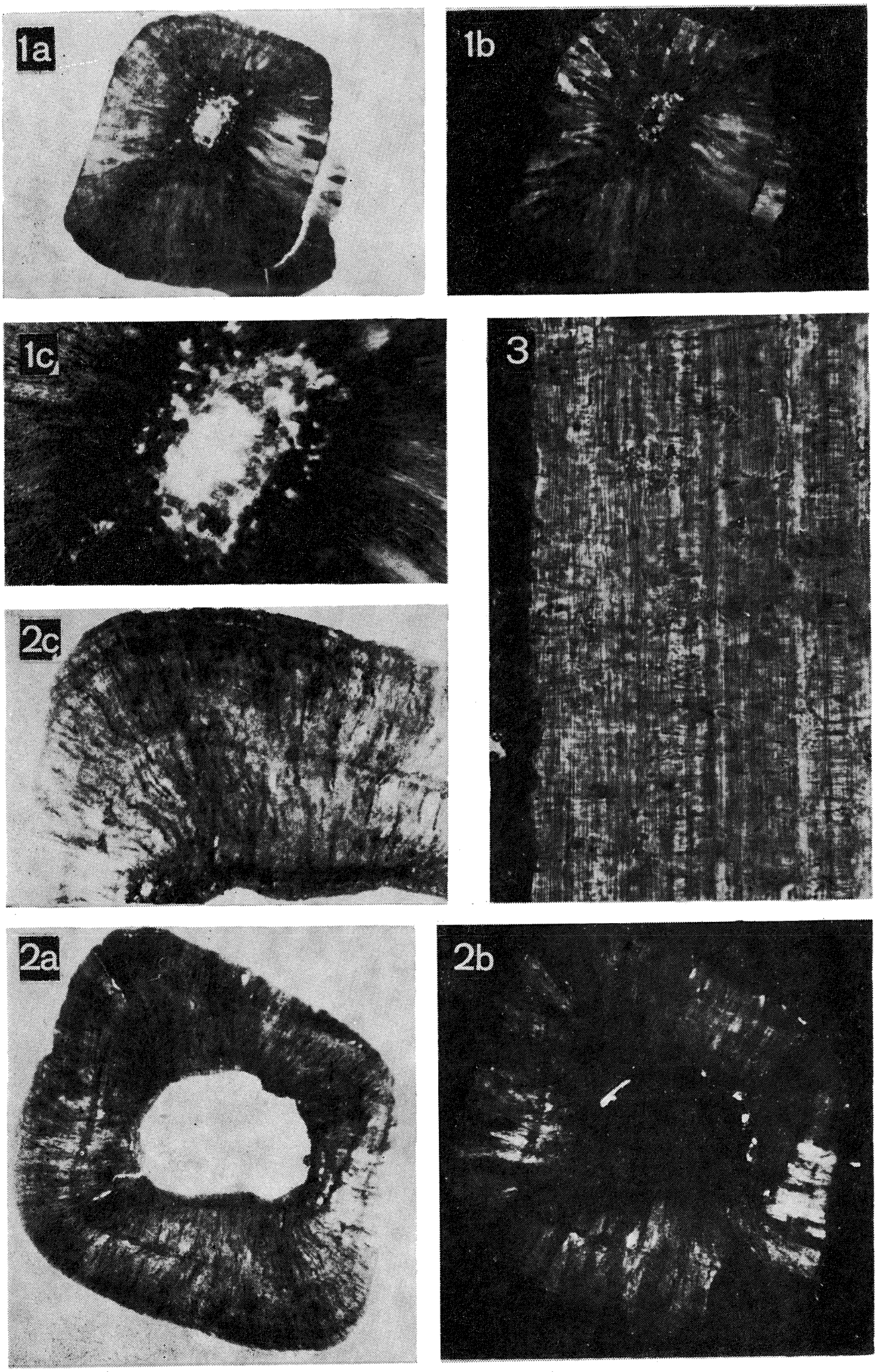
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section (*see* MILNE-EDWARDS & HAIME 1850, Pl. 7, Figs 4, 4c and 4d). In the collected material from the Korytnica Clays, the specimens showing an ellipsoidal section (*see* MILNE-EDWARDS & HAIME 1850, Pl. 7, Figs 4a, 4b and 4e) are however missing. The external surface of the specimens of *Graphularia transaedina* sp. n. and *G. wetherelli* MILNE-EDWARDS & HAIME is almost identical.

The only Miocene axial rods reported by BRANCO (1885) and determined as *Graphularia* sp. from Baden in the Vienna Basin are circular in their transverse section.

DIAGENETIC ALTERNATIONS IN *GRAPHULARIA TRANSAEDINA* SP. N.

All the morphological characters of *Graphularia transaedina* sp. n were noted in the specimens with nonaltered primary microstructure. In other investigated specimens either altered and nonaltered portions have been found in the same specimens (Pl. 3, Figs 6a-c; Pl. 7, Fig. 1) or a complete diagenetic alternation has been recognized, the latter leading to the total obliteration of tiny details and leaving only gross morphology (Pl. 3, Fig. 7; Pl. 7, Fig. 2).

Specimens with primary microstructure are white, while its most easily observed character of diagenetic alternation is the change of colour into brown. This process starts in zones of a higher organic content, *i.e.* between particular growth layers, but no space between altered and nonaltered portions was observed (Pl. 3, Figs 6a, c; Pl. 7, Fig. 1). The alternation has a neomorphic character, however during it all details as fan-shaped crystals, subcrystals, and canals are destroyed and in their place large blocky crystals of calcite are formed (Pl. 7, Figs 1—2). Nevertheless they often show similar optical orientation as primary crystals (Pl. 3, Fig. 7). The neomorphic crystals are clear with yellow-brown tint and pseudopleochroic, similarly as the primary crystals. Sometimes in a pore space between growth layers and in the central hollow part of the rod, sparry calcite cement has developed (Pl. 3, Figs 6a, c; Pl. 6, Fig. 1b).

All the skelatal structures of Recent Octocorallia are usually built of calcite (BATHURST 1975; SORAUF 1980; FRANC, HUC & CHASSAGNE 1974), particularly the sclerites are built of high-Mg calcite. The same concerns the axial rod of *Veretillum cynomorium* (PALLAS) which is also built of calcite, but informa-

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PLATE 2

1 — Transverse thin section of the axial rod, to show distribution of crystals, and the central core with granules: *1a* ordinary light, × 30; *1b* crossed nicols, × 30; *1c* granules; ordinary light, × 100

2 — Transverse thin section of the axial rod, to show growth layers and crystal distribution: *2a* ordinary light, × 73; *2b* crossed nicols, × 73; *2c* part of the axial rod with growth layers and cavities after chimney cells; ordinary light, × 110

3 — Longitudinal thin section of the axial rod (central core at left) with delicate striation caused by canals after collagen fibrils; ordinary light, × 270

tion on its Mg content is lacking (*see* FRANC, HUC & CHASSAGNE 1974; LEDGER & FRANC 1978). Both altered and nonaltered specimens of *Graphularia transaedina* sp. n. were investigated by means of X-ray analysis. Well preserved specimens with nonaltered microstructure are built entirely of calcite with Mg content about 7 mole % of $MgCO_3$ (main peak at 29.65° which as equal 3.0138 Å), what is a rare case of preservation of Mg-calcite in the fossil state (IWASIŃSKA, NARKIEWICZ & PISERA 1981). Altered specimens are built of calcite with much lower Mg content, about 2 mole % of $MgCO_3$ (main peak at 29.48° which is equal 3.0298 Å).

GENUS *GRAPHULARIA* AND ITS RELATION TO RECENT SEA PENS

The genus *Graphularia* has been established by MILNE-EDWARDS & HAIME (1850) upon small fragments from the London Clays (Eocene). All the type specimens, of variable section outline, have been regarded as conspecific and determined as *Graphularia wetherelli* MILNE-EDWARDS & HAIME, 1850. According to MILNE-EDWARDS & HAIME (1850), the axial rod of the species, even more than a foot in length, displays a cylindrical shape in its lower part, and subtetrahedral in the upper one; by its section outline it difers from the genera *Virgularia* LAMARCK, 1816, *Pavonaria* SCHWEIGER, 1820 (= *Funiculina* LAMARCK, 1816; non *Pavonaria* KOELLIKER, 1869 = *Balticina* GRAY, 1870), and *Umbellularia* LAMARCK, 1801 (= *Umbellula* CUVIER, 1798); by the morphology of the external surface and by the lack of a distinct tapering it differs from *Lituaria* MILNE-EDWARDS & HAIME, 1850; and by its length it also differs from *Veretillum* CUVIER, 1798.

The successive species within the genus *Graphularia* have been established upon the general features, precisely upon the section outline and

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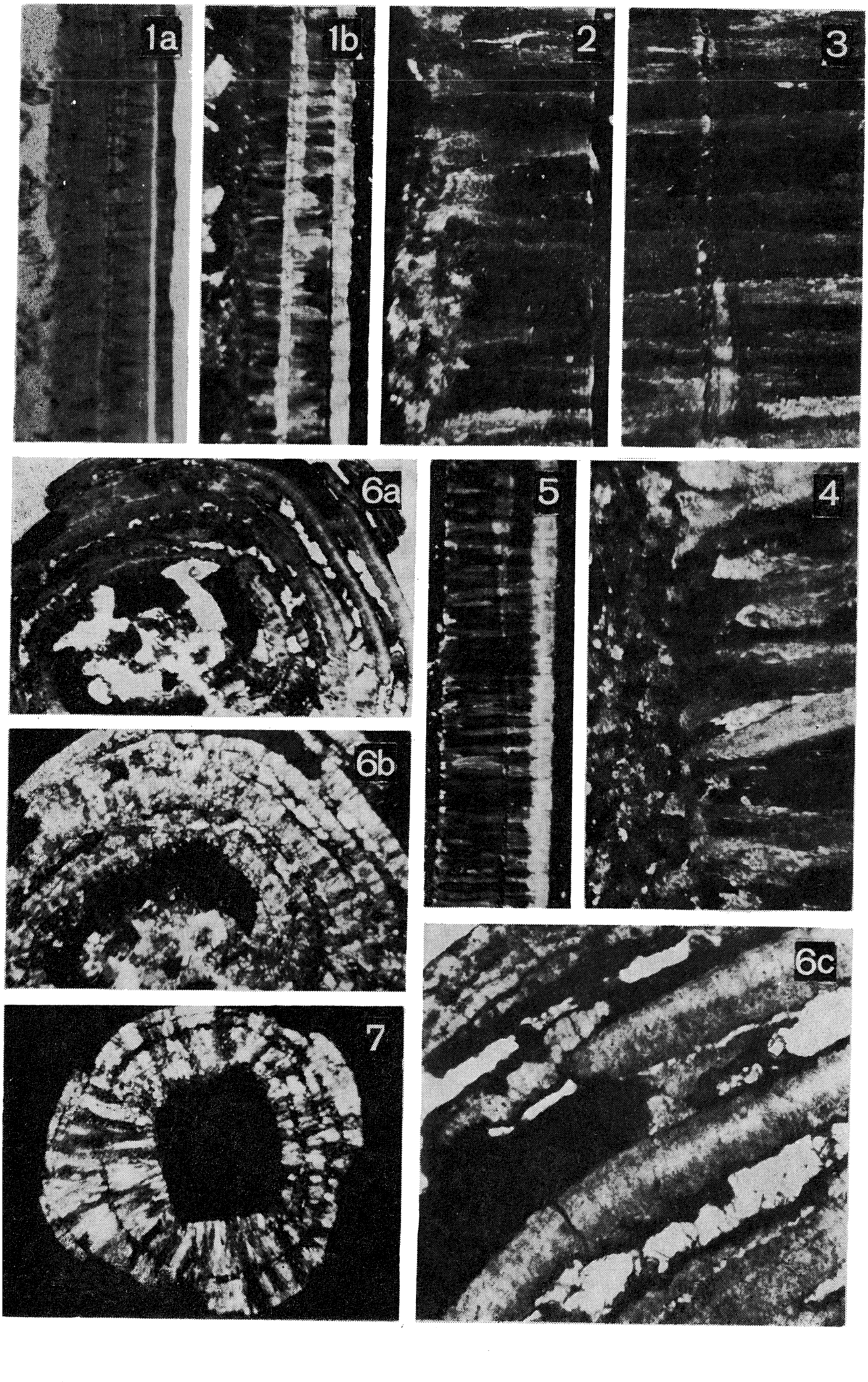
PLATE 3

1 — Longitudinal thin section of the axial rod, to show disposal of crystals (central core at left); outer and middle layers partly altered; *1a* ordinary light, *1b* crossed nicols, both × 30
2 — Longitudinal thin section, to show columnar to fan-shaped crystals oriented perpendicularly to the axial rod; crossed nicols, × 120
3 — Regularly developed crystals cutting (without optical reorientation) a growth discontinuity; thin section, crossed nicols; × 120
4 — Transition from granules into columnar to fan-shaped crystals; longitudinal thin section, crossed nicols; × 120
5 — Regularly developed columnar to fan-shaped crystals with the same optical orientation almost in the whole cortical zone; outer layer with different optical orientation; thin section, crossed nicols; × 36
6 — Specimen with altered microstructure and parts of primary microstructure (*black*) still preserved; transverse thin section; *6a* ordinary light, × 25; *6b* crossed nicols, × 25; *6c* ordinary light, × 100
7 — Completely altered specimen, to show crystal disposal and accentuation of growth layers; transverse thin section, crossed nicols; × 25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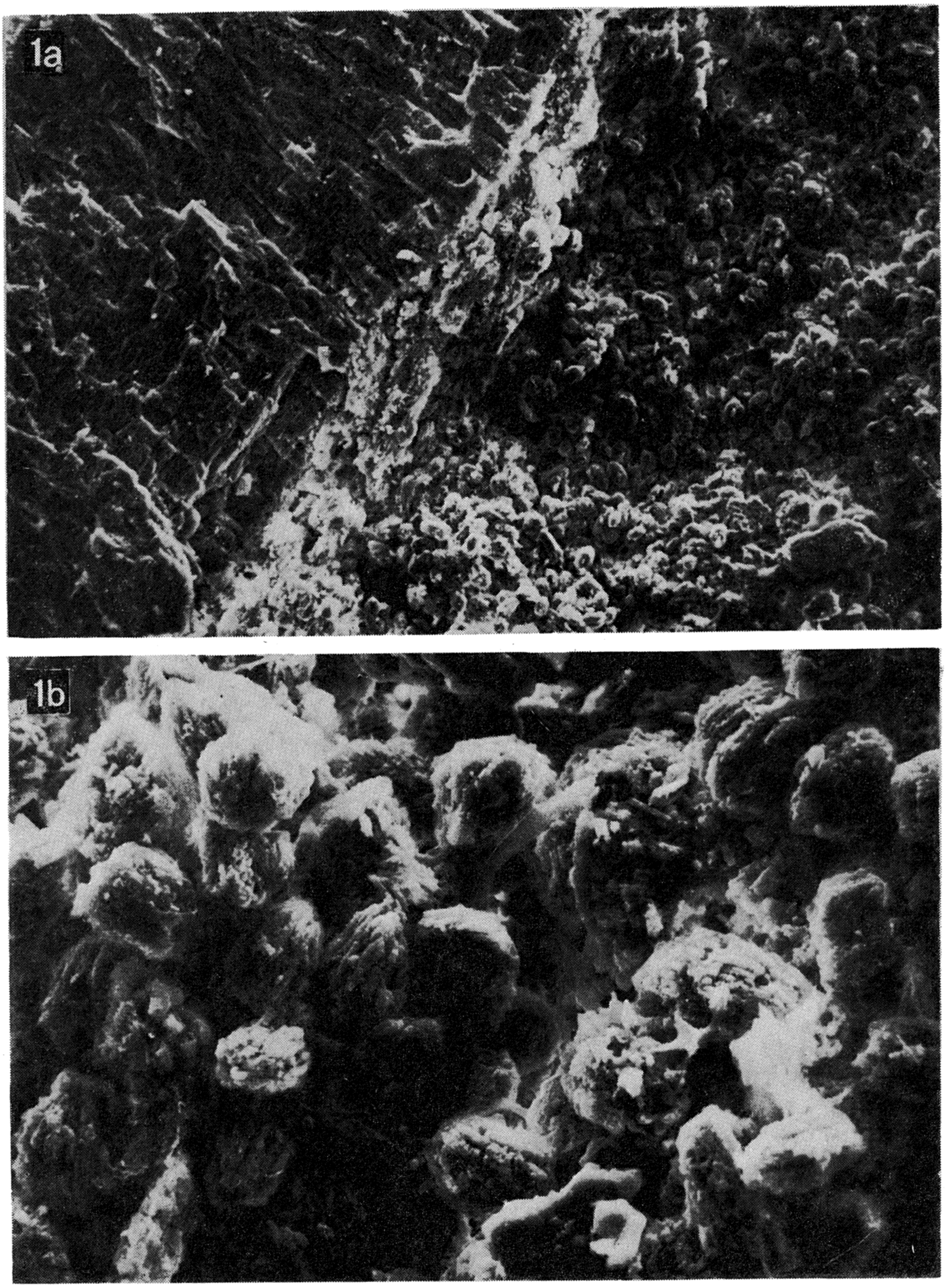
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the size of axial rods (see *e.g.* PRATZ 1883, BRANCO 1885, VOIGT 1958, SHAPIRO & RAMSDELL 1965). These axial rods, coming from deposits of Late Cretaceous to Neogene age, display the section outline varying from circular (*Graphularia* sp. of BRANCO 1885), oval and subtrigonal (*Graphularia brauni* BRANCO, 1885), subtetragonal (*G. quadrata* VOIGT, 1958), to irregular (*G. meijeri* VOIGT, 1958). Such characteristics, however, extends largely the original diagnosis of the genus, given by MILNE-EDWARDS & HAIME (1850, p. LXXXIII).

The presented review allows to conclude that the shape variability of the axial rods within the extinct genus *Graphularia* is much greater than within anyone of the present-day sea pens. It is thought that the genus *Graphularia* contains diverse genera of sea pens, both ancient and extant. Unsufficient state of the knowledge, very poor indeed, on the microstructure of axial rods and its significance for the taxonomy at ranks lower than the order (*cf.* SHAPIRO & RAMSDELL 1965), makes further considerations impossible. An opinion expressed by BAYER (1955, 1956) that *Graphularia* is congeneric with Recent *Stylatula* VERRILL, 1864, cannot therefore be justified.

In thin sections, the axial rods of the Recent genus *Stylatula* display a more regular development of columnar calcite. When sectioned transversally, the axial rods of *Stylatula* appear to be composed of very regular, fan-shaped crystals, arranged radially and continuing throughout the whole axis. In *Graphularia transaedina* sp. n. the crystals are shorter and less regular.

A disputable problem is the presence of the so-called tubules of BAYER (1955). These structures have first been noted by KOELLIKER (*fide* BAYER 1955) in *Stylatula*, and recognized (BAYER 1955) also in *Graphularia wetherelli* MILNE-EDWARDS & HAIME. Unfortunately, they are not recognizable in the photographs presented by BAYER (1955). It seems that the structures BAYER (1955) speaks about, are really the cavities after chimney cells, as it is evident from the descriptions of *Graphularia*, given by SHAPIRO & RAMSDELL (1965) who have not noted any structures comparable to the discussed tubules.

The microstructure pattern in *Graphularia transaedina* sp. n. is surprisingly similar to that recognized (FRANC, HUC & CHASSAGNE 1974; LEDGER & FRANC 1978) in the Recent species *Veretillum cynomorium* (PALLAS). The latter species, however, as stated already by MILNE-EDWARDS & HAIME (1850, pp. 41—42), has the axial rod highly rudimentary, and thus a congeneric affinity cannot be taken into account.

PLATE 4

1a — Longitudinal broken surface, to show the central core with numerous granules and the cortical zone with cavities after chimney cells; *SEM* × 172

1b — Calcareous granules in the central core; broken surface, *SEM* × 918

Nevertheless, the discussed similarity indicates either a relatively close relationship between these genera, or a useless importance of microstructural morphologies for the taxonomy at ranks lower than the order.

For further interpretation, an analysis of the microstructure in the Recent genus *Kophobelemnon* ASBJÜRSEN, 1856, should be recommended. The axial rod in this genus, to judge by the available illustration (DELAGE & HEROUARD 1901, Fig. 605 and Pl. 54), is similar to *Graphularia transaedina* sp. n. in its size and shape, although it is more slender. The families Kophobelemnidae GRAY, 1860, and Veretillidae HERKLOTS, 1858, belong to the same suborder, Sessiliflorae KÜKENTHAL, 1915. Their systematic affinity is closer than with the family Virgulariidae VERRILL, 1868, which contains the genus *Stylatula*, and to which the genus *Graphularia* has been included by BAYER (1956); the family itself being placed within the order Subselliflorae KÜKENTHAL, 1915. Consequently, the present authors regard the genus *Graphularia* as still not attributable to any definite family and suborder of the pennatulacean corals.

Acknowledgements

The authors express their most sincere thanks to Dr. S. FLORIS, Geologisk Museum in Copenhagen, for supplying xerox-copies of some not easily available papers.

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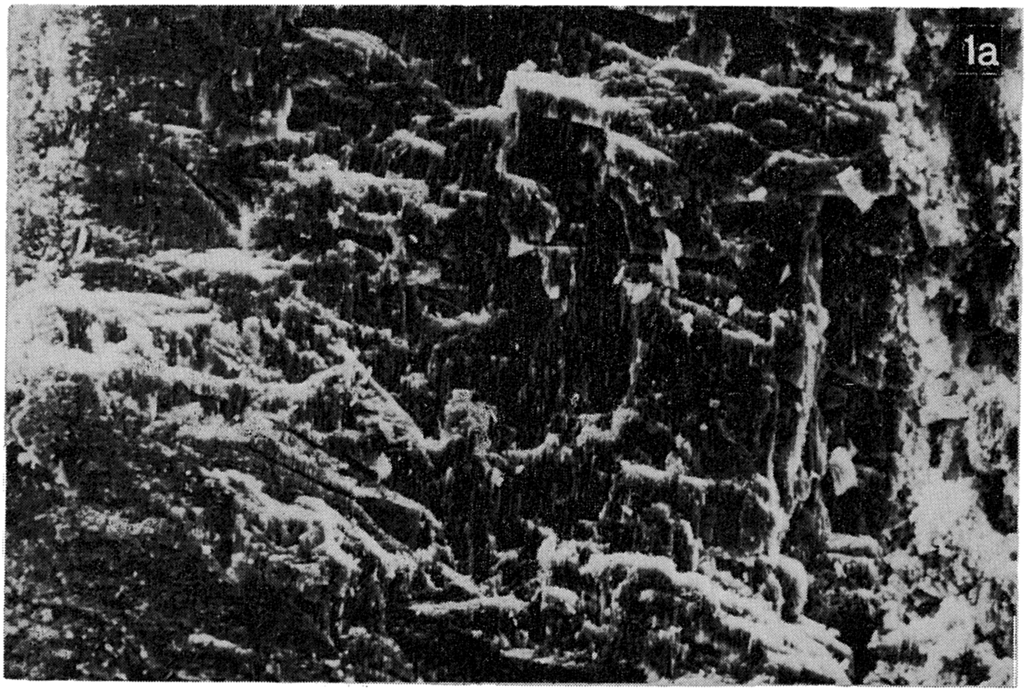
PLATE 5

1a — Numerous perpendicular or oblique cavities after chimney cells, and longitudinal striation; *SEM* × 275

1b — Longitudinal canals after collagen fibrils; *SEM* × 1300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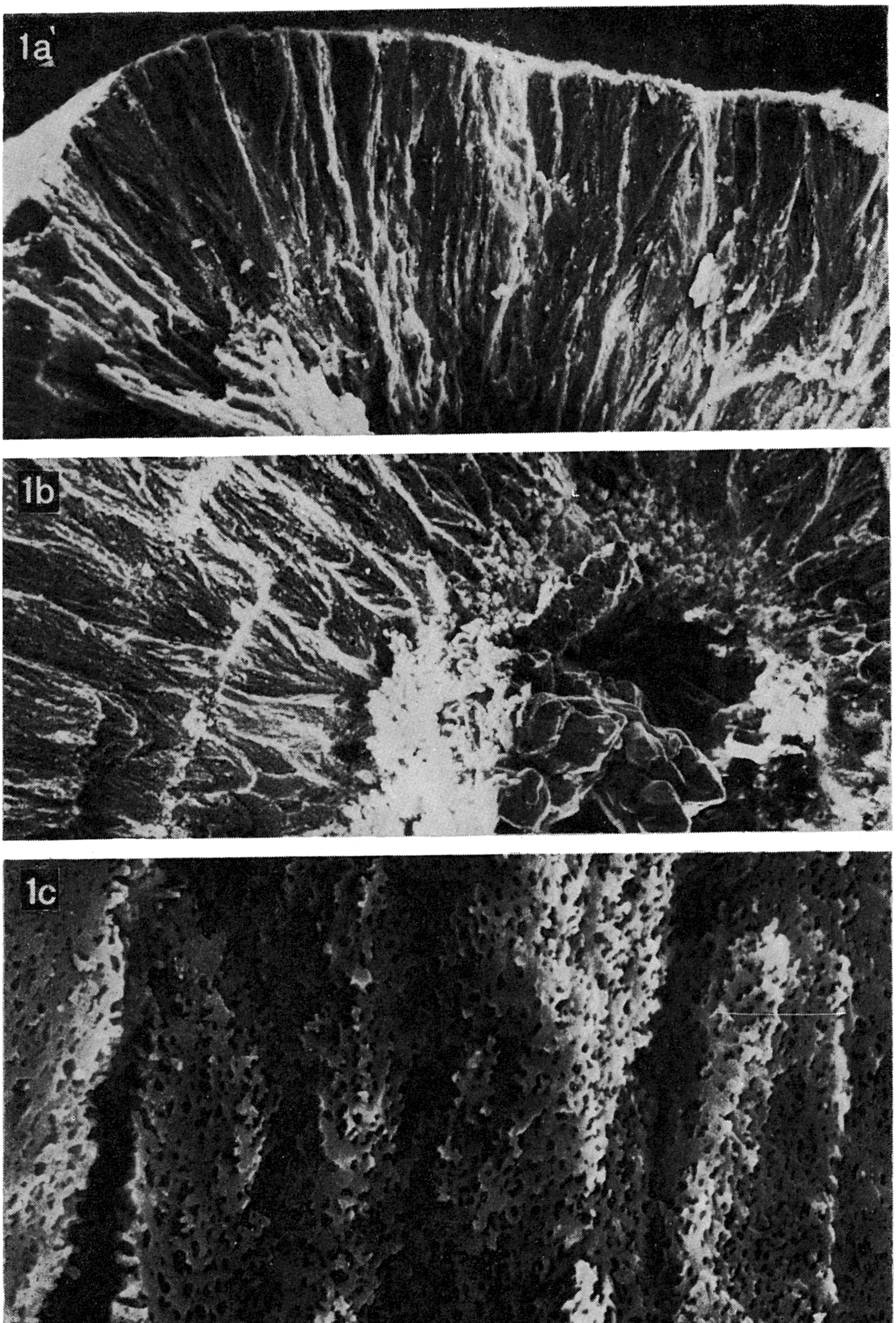
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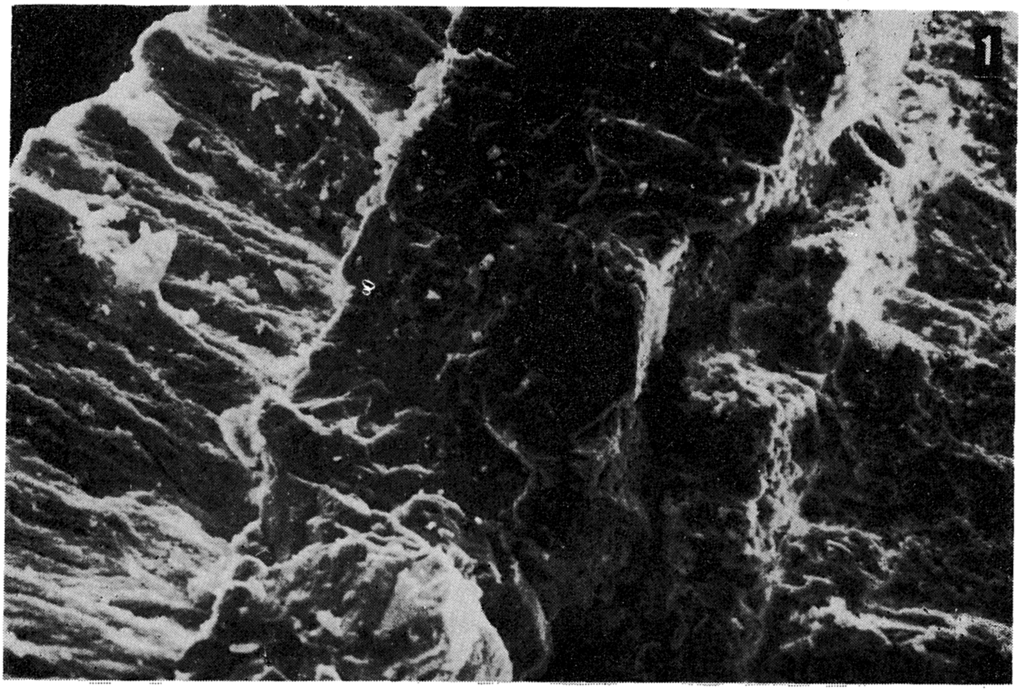
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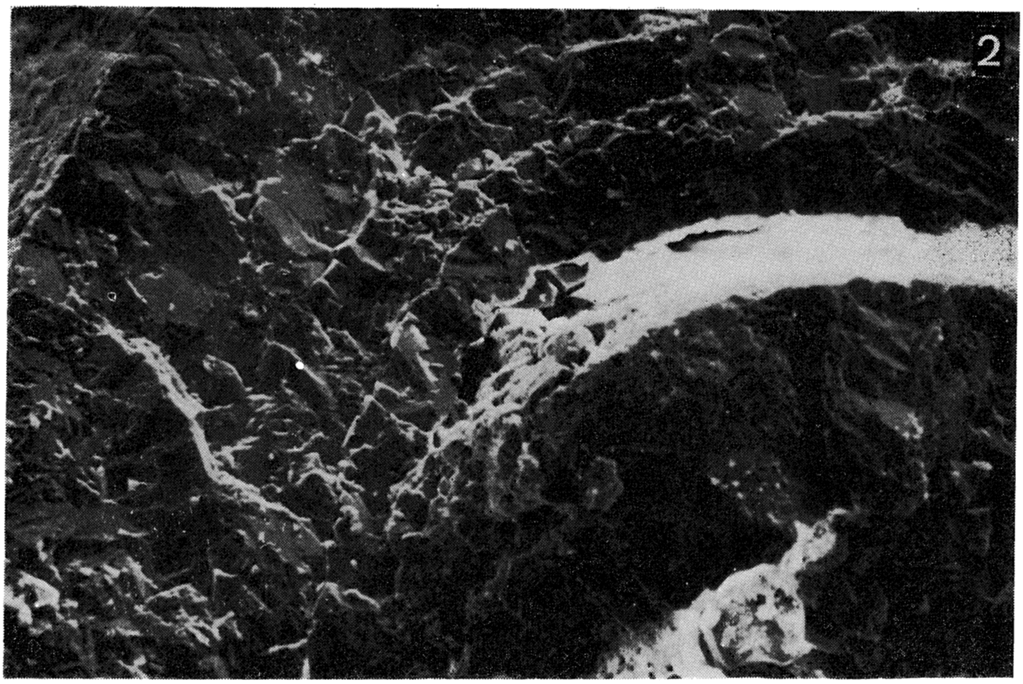
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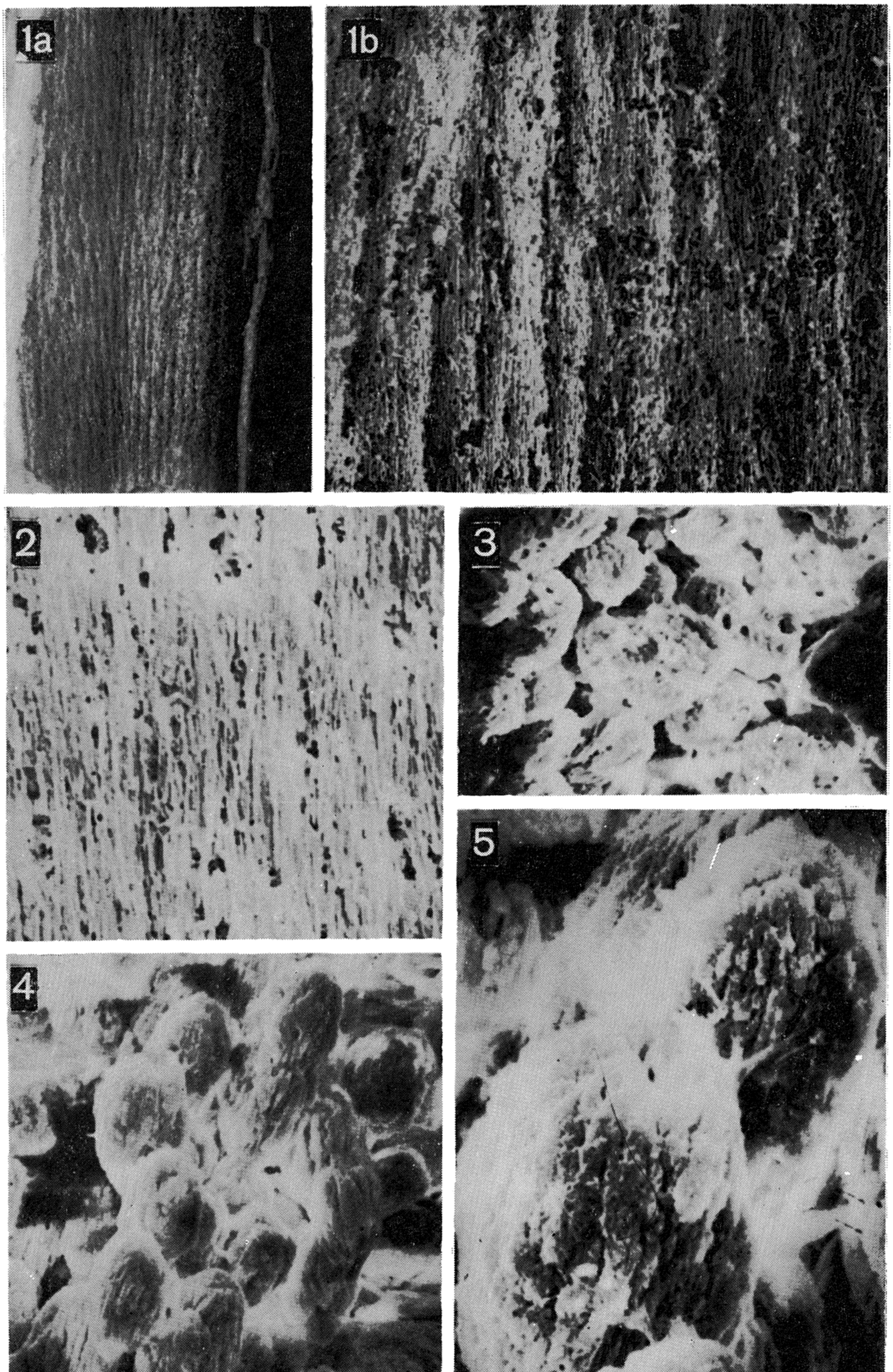
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PLATE 6

Graphularia transaedina sp. n.; transverse broken surface of the axial rod

1a — Cortical zone, to show radially disposed columnar to fan-shaped crystals, and small elongated cavities after chimney cells; *SEM* × 200
1b — Cortical zone and central core, to show transition from granules into fan-shaped crystals of the cortical zone; in the hollow part blocky calcite cement is visible; *SEM* × 150
1c — Cortical zone: numerous openings of the canals after collagen fibrils and large cavity after chimney cell are visible; *SEM* × 2600

PLATE 7

Alternation of the primary microstructure; transverse broken surface, *SEM*

1 — Nonaltered outermost layer of the cortical zone with radial crystals and altered inner layer built of blocky neomorphic calcite; × 340
2 — Completely altered microstructure with accentuated growth layers built of blocky neomorphic calcite (cleavage surfaces are visible); × 200

PLATE 8

1a-1b — Outer surface of the axial rod: 1a — fresh surface exposed by peeling-off the outermost layer, *SEM* × 30; 1b — numerous openings after chimney cells, and canals after collagen fibrils; *SEM* × 300
2 — Outer surface of another axial rod; *SEM* × 900
3 — Granules from the central core of the axial rod; *SEM* × 500
4 — Another example of granules; *SEM* × 950
5 — Granules in high magnification, to show canals after collagen fibrils; *SEM* × 2700